THE HAIL-THUNDERSTORM RATIO [1]

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ON pages 729 and 730 of the 1941 *Yearbook of Agriculture*, "Climate and Man," there are maps showing the average annual number of days with thunderstorms and days with hail, respectively. The highest frequencies of annual hail occurrence are eight at Cheyenne, five in the vicinity of Modena-Pocatello-Helena, four over an area including eastern Wyoming, eastern Colorado, Kansas, and Northern Oklahoma. About half the country has less than three annual occurrences. Comparing these frequencies with the annual number of thunderstorm days, the ratio of hail to thunderstorm occurrence becomes as high as 20 percent in some places, and much less in most places.

An examination of random monthly climatic summaries indicated, however, that the number of days on which hail occurred anywhere in a State was usually a much higher percentage than 20 of the number of days with thunderstorms in that State. Almost always the dates of occurrence were the same.

To check that indication the number of days with hail and also the number of days with thunderstorms were counted for the 25 years from 1916 to 1940, inclusive, in the State of Iowa and in the Maryland-Delaware-District of Columbia climatic section. Iowa was chosen because it had the best collection of climatic summaries and the other section was chosen because a comparison of the hail-thunderstorm ratio could be made with detailed data on the same for Washington, D. C. The data for Iowa were compared with the point data from Kansas City, Mo., because a complete, lengthy record from the latter was also available.[2]

Tables 1 and 2 show the data on days with thunderstorms, hail, and tornadoes in the two sections. Although the tornado totals are included in the tables they are not plotted in the accompanying figure showing the comparative annual variation of frequencies because the tornado numbers are too small for adequate representation. However, it may be said that, where the tornado occurrences are appreciable, as in Iowa, the monthly variation in average number of occurrences forms a curve which is a flattened version of the hail-variation curve. In the Maryland-Delaware-District of Columbia area, the tornado occurrences are too few and the resulting curve of monthly variation too flat to make comparison with the hail curve possible.

In the figure, titled "Comparative Hail-Thunderstorm Frequencies," the data for the station and the area are compared. For both point and area, the frequency of hail increases with the frequency of thunderstorms. However, the ratio of hail to thunderstorm occurrences varies in, generally, an opposite sense, reaching a minimum at the time of the maximum occurrence of both thunderstorms and hail during the summer or as late as September. The greater ratios of the spring and winter months can be considered evidence that frontal rather than air-mass phenomena are most favorable to the production of hail in thunderstorms—but the relatively low altitudes of the zero isotherm must also be considered as an important contributing factor. At Cheyenne, for example, the low height of the zero isotherm (or, more accurately, the zero wet-bulb) above station elevation has much to do with the hail maximum at that point. There is simply less opportunity for melting or evaporation of the hailstone. The negligible number of occurrences at Key West or other tropical stations also bears this out. However, even in the latter comparison, consideration of frontal activity would yield similar theoretical results.

The State-wide or section-wide days of occurrence of thunderstorms or hail exceed the occurrences as reported by the single station or, as a matter of fact, the occurrences reported by any station within the State or section. That this should be so is obvious from the consideration that if large enough an area—for instance, the area of the earth—were used, then every day would be a thunderstorm and a hail day—perhaps even a tornado day. However, this fact does not cancel the validity of the increase in occurrences observed in the State-wide data. The thunderstorm and, to a greater degree, the hailstorm are phenomena of small areal extent. Thunderstorms are officially reported only when thunder is heard and the audibility of thunder, according to C. E. P. Brooks [3], is 10 or 12 miles under favorable circumstances and, under normal circumstances, the area within which thunder can be heard is about 113 square miles, that is, the radius of audibility is 6 miles. Hence, if only first-order stations, widely spaced, are used to study frequency of occurrences, many occurrences of thunder will be missed. Fewer would be missed by such a sparse network if lightning were the phenomenon that had to be observed. Hail is neither seen nor heard at any appreciable distance, its total area of occurrence being often of the order of 20 square miles. A sparse network will thus miss more hailstorms than thunderstorms. The use of areal occurrences corrects these faults although the exact area to be used for a proper correction is problematical and an academic question in this case, since the areal data are limited to climatic sections or States. (In a study of "Lightning Storms and Forest Fires in the State of Washington" by G. W. Alexander in the March 1927 MONTHLY WEATHER REVIEW, it is shown that the use of a dense network in that region doubled, tripled and quadrupled the days with thunderstorms indicated by W. H. Alexander's isoceraunics for the period 1904–23 [4]).

Assuming, then, that the areas are not too large to be significant, in the two examples cited the thunderstorm frequencies are approximately doubled while the hail occurrences are increased five- to ten-fold. This results in increases in the hail-thunderstorm ratios—although the pattern of the monthly variation of the ratio is retained. Comparing Iowa and Kansas City, the latter's annual ratio is increased from about 8 to 42 percent. The peak station ratios are 22 and 24 in March and November; the peak state ratios are 63, 62, and 54 in February, April, and December, respectively. The minimum ratio is 2 percent in July–August at the station, and 25 in September in the State. Comparing Washington, D. C., with its climatic section, the former's annual ratio is increased from about 4 to 19 percent. The station peaks are 12 in February and 45 in December (the latter being unusually out of line) and the section

[1] Section of an extensive report on "Thunderstorm Rainfall" being prepared by the Hydrometeorological Section for the Corps of Engineers, War Department.

[2] Hamrick, A. M. and Martin H. H. "Fifty Years of Weather in Kansas City, Mo.", MO. WEA. REV. SUPPLEMENT NO. 44, 1941.

[3] Brooks, C. E. P., "The Distribution of Thunderstorms over the Globe," British Meteorological Office Geophysical Memoirs No. 24, 1925.

[4] Alexander, William H., "The Distribution of Thunderstorms in the United States, 1904–1923," MO. WEA. REV., vol. 52, July 1924. The values are not changed appreciably in the same author's study for the period 1904–33 in the MO. WEA. REV., vol. 63, May 1935, nor in the "Climate and Man" chart.

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peaks are 29 in April and 22 in November. The station minima range between 0 and 2 in January and June through September; the section minima are 4 in December and 8 in both January and September.

It is worth mentioning that examination of the areal data reveals that in the winter and spring months, particularly the winter, the number of hail days often equals the number of thunderstorm days and sometimes even exceeds them. Some of this may be attributed to poor observation since it is well known that the layman often confuses hail with sleet, but the tendency is probably real and stresses the importance of the height of the zero isotherm (lowest in the winter) in influencing the production of hail and the possible production of hail without thunder, since the latter originates from an electrical discharge which arises from the breakup or motion of raindrops rather than frozen drops. Some of the winter hail occurrences are described by the observers as small hail, a hydrometeor apparently most frequent on the Pacific coast. For that section, incidentally, such occurrences have not been included in the hail-distribution chart on page 730 of "Climate and Man." Otherwise, as is evident from Lemons' hail maps,[5] at least a secondary maximum would appear along the Pacific coast.

[5] Lemons, Hoyt: "Semimonthly Distribution of Hail in the United States," Mo. Wea. Rev. vol. 71, July 1943.

The particular suggestion that the present writer has to offer is that further study be made of the areal hail-thunderstorm ratio by climatic section centers. The evidence seems convincing that the commonly held notion that hail occurrences in thunderstorms are comparatively few is erroneous. Some indication of the validity of the areal method, when States of average size are used, is the following fact. While Iowa has an area of 56,000 and Maryland-Delaware-District of Columbia an area of only 12,700 square miles, the areal annual hail-thunderstorm ratio is in both cases about five times the point ratio. Further research may show that to hold elsewhere, in which case a fivefold increase of the point ratio would yield the proper ratio, approximately, for any area. It is interesting to note that five is also the ratio of the average area of thunder audibility to the average area of a hailstorm, as mentioned earlier in this paper. For any further investigation, however, inspection of State climatic summaries indicates that in most cases it will be necessary to go back to the original manuscript records of cooperative stations for the basic data needed for a summary of areal frequencies.

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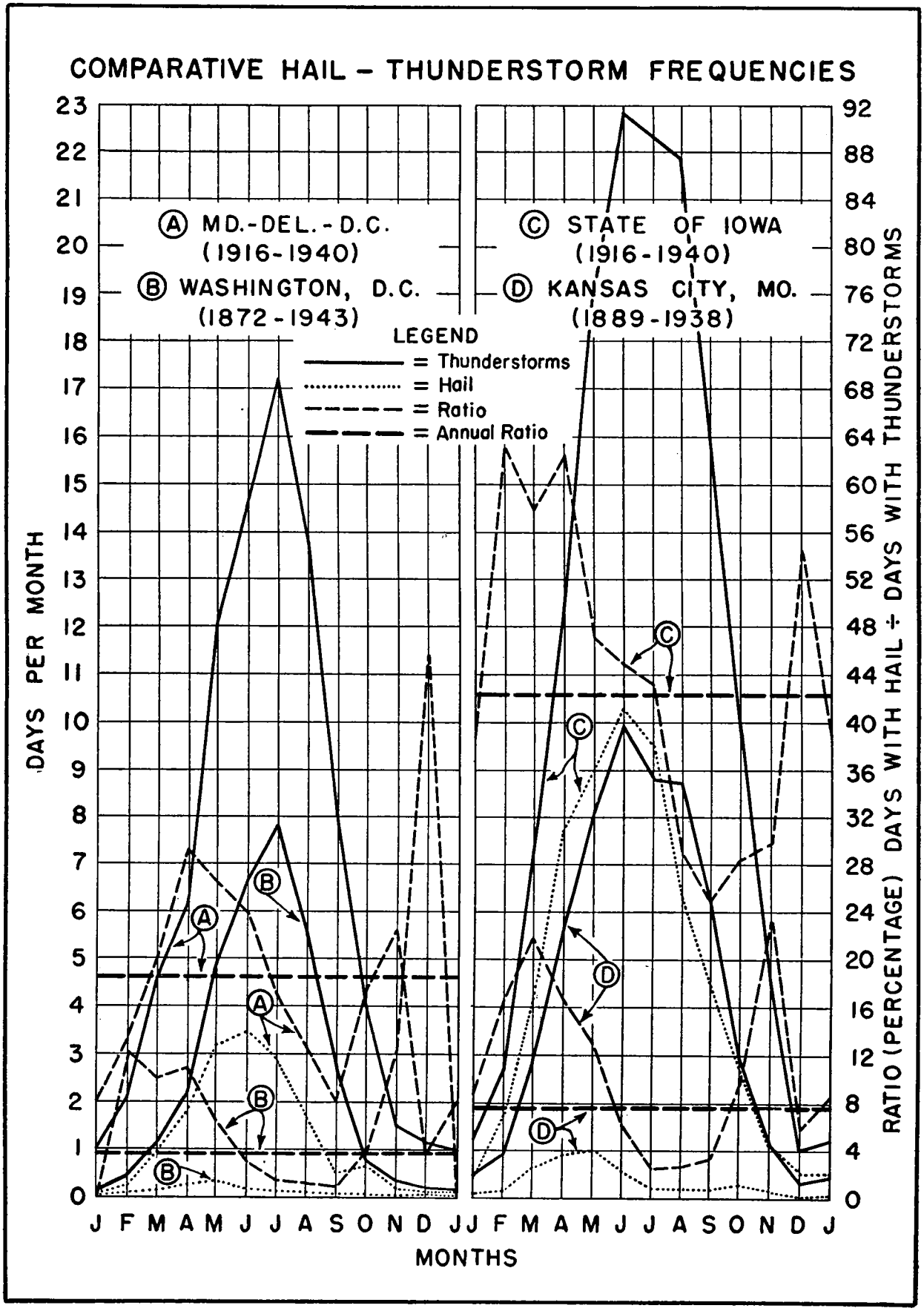

TABLE 1—*Thunderstorm-hail-tornado * frequencies*

(A) MARYLAND-DELAWARE-DISTRICT OF COLUMBIA (1916–40) vs. (B) WASHINGTON, D. C. (1872–1943)

	Jan.			Feb.			Mar.			Apr.			May			June		
	⛈	H	T	⛈	H	T	⛈	H	T	⛈	H	T	⛈	H	T	⛈	H	T
Totals (A)	25	2	0	53	7	2	116	23	0	150	44	2	278	78	5	350	87	2
Totals (B)	10	0	—	33	4	—	79	8	—	155	17	—	341	21	—	467	13	—
Means (A)	1.0	0.1	0	2.1	0.3	0.1	4.6	0.9	0	6.2	1.8	0.1	12.1	3.0	0.2	14.6	3.5	0.1
Means (B)	0.1	0	—	0.5	0.1	—	1.1	0.1	—	2.2	0.2	—	4.8	0.3	—	6.6	0.2	—
Percent ratio H/⛈ (A)		8.0			13.2			19.8			29.3			26.4			23.8	
Percent ratio H/⛈ (B)		0			12.1			10.1			11.0			6.2			2.8	

	July			Aug.			Sept.			Oct.			Nov.			Dec.		
	⛈	H	T	⛈	H	T	⛈	H	T	⛈	H	T	⛈	H	T	⛈	H	T
Totals (A)	414	73	5	340	44	6	184	12	2	88	16	1	31	7	3	26	1	0
Totals (B)	554	8	—	390	5	—	193	2	—	53	2	—	24	3	—	11	5	—
Means (A)	17.2	2.9	0.2	13.8	1.8	0.2	8.0	0.5	0.1	4.0	0.7	0.0	1.5	0.3	0.1	1.1	0.0	0
Means (B)	7.8	0.1	—	55	0.1	—	2.7	0.0	—	0.8	0.0	—	0.3	0.0	—	0.2	0.1	—
Percent ratio H/⛈ (A)		17.0			12.7			8.0			17.5			22.6			3.8	
Percent ratio H/⛈ (B)		1.4			1.3			1.0			3.8			12.5			45.5	

⛈=Thunderstorms, H=hail, T=tornadoes (All: Days with —).
*Tornado frequency for area only, 1880–1942.

TABLE 2.—*Thunderstorm-hail-tornado* frequencies*

(C) IOWA (1916–40) vs. (D) KANSAS CITY, MO. (1889–1938)

	Jan.			Feb.			Mar.			Apr.			May			June		
	⛈	H	T	⛈	H	T	⛈	H	T	⛈	H	T	⛈	H	T	⛈	H	T
Totals (C)	31	12	0	67	43	1	182	105	11	307	192	17	477	224	34	572	257	47
Totals (D)	24	2	—	45	7	—	144	31	—	281	44	—	406	52	—	495	30	—
Means (C)	1.2	0.5	0	2.7	1.7	0.0	7.3	4.2	0.4	12.3	7.7	0.7	19.1	9.0	1.4	22.9	10.3	1.9
Means (D)	0.5	0.0	—	0.9	0.1	—	2.9	0.6	—	5.6	0.9	—	8.1	1.0	—	9.9	0.6	—
Percent ratio H/⛈ (C)		38.7			63.2			57.7			62.5			47.0			44.9	
Percent ratio H/⛈ (D)		8.3			15.6			21.7			15.6			12.8			6.1	

	July			Aug.			Sept.			Oct.			Nov.			Dec.		
	⛈	H	T	⛈	H	T	⛈	H	T	⛈	H	T	⛈	H	T	⛈	H	T
Totals (C)	559	239	28	548	157	13	401	109	14	243	69	7	114	34	1	24	13	0
Totals (D)	439	11	—	435	11	—	311	10	—	148	14	—	60	7	—	18	1	—
Means (C)	22.4	9.6	1.1	21.9	6.3	0.5	16.0	4.4	0.6	9.7	2.8	0.3	4.6	1.1	0.0	1.0	0.5	0
Means (D)	8.8	0.2	—	8.7	0.2	—	6.2	0.2	—	3.0	0.3	—	1.2	0.1	—	0.4	0.0	—
Percent ratio H/⛈ (C)		42.8			28.6			24.7			28.4			29.8			54.2	
Percent ratio H/⛈ (D)		2.5			2.5			3.2			9.4			23.3			5.6	

⛈=Thunderstorms, H=hail, T=tornadoes (all days with —).
*Tornado frequency for area only, 1880–1942.